Tri-Gas Thruster Performance Characterization

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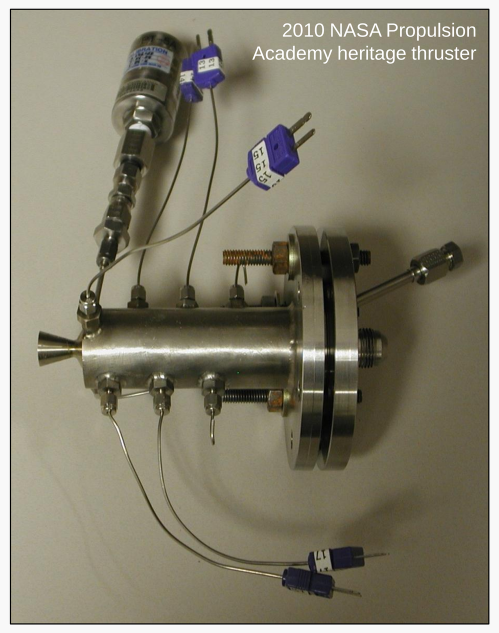
PROJECT BACKGROUND

- Reaction control systems historically have used cold gas thrusters, which are simple and safe, but have low specific impulse
- Thruster performance can be improved by passing tri-gas (an inert monopropellant mixture of He, O_2, and H_2) through a catalyst bed
- Growing interest in "green" propellant developments

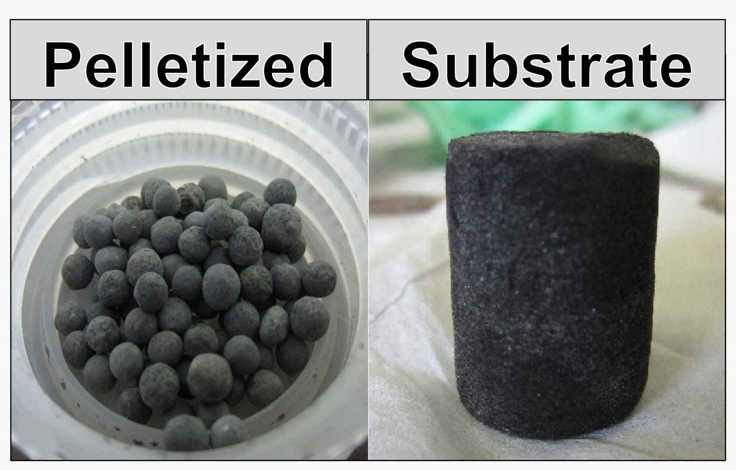


OBJECTIVES

1) Characterize the performance of a tri-gas thruster as a function of varying catalyst type, length, and initial temperature.
2) Derive thrust and specific impulse from pressure, temperature, and mass flow rate data measured through testing
3) Optimize thruster configuration based on the assessment of the candidate catalysts' reactivity

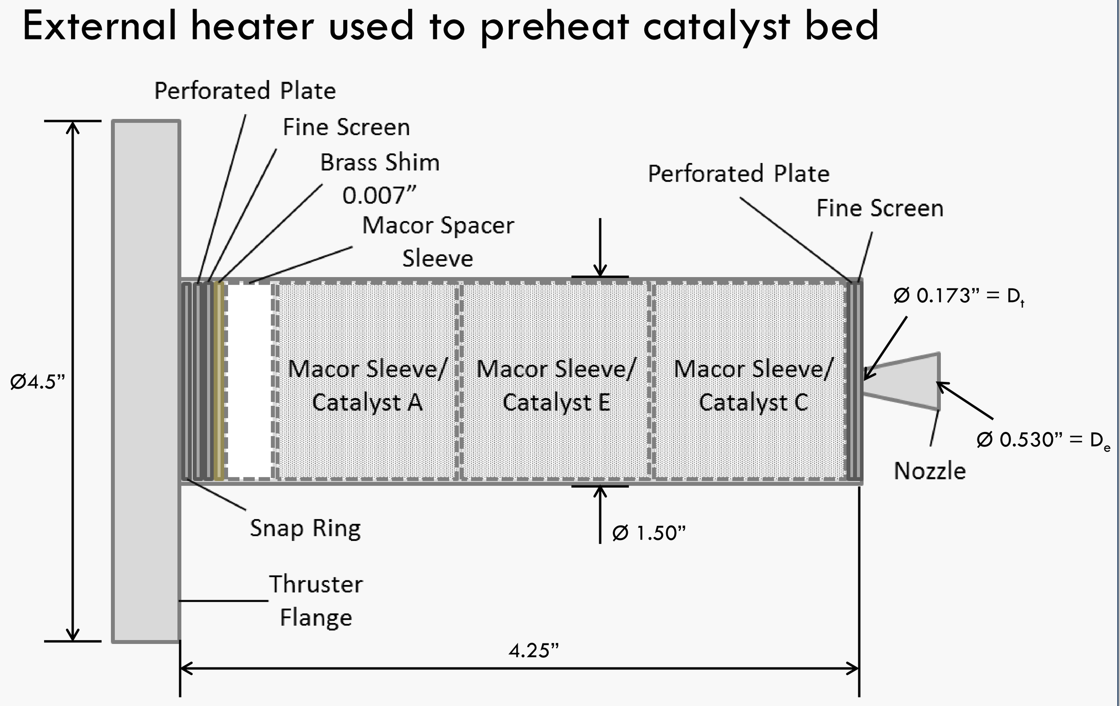
CATALYST DESCRIPTION

When tri-gas is passed through the catalyst, the hydrogen and oxygen gases become reactive and form water vapor. The heat of formation of this reaction imparts thermal energy into the exiting gas, which subsequently increases the thruster specific impulse. The performed tests investigated the characteristics of a platinum coated catalyst, which was expected to perform better than previously tested palladium samples. Both a pelletized and substrate catalyst were used for this iteration of testing.

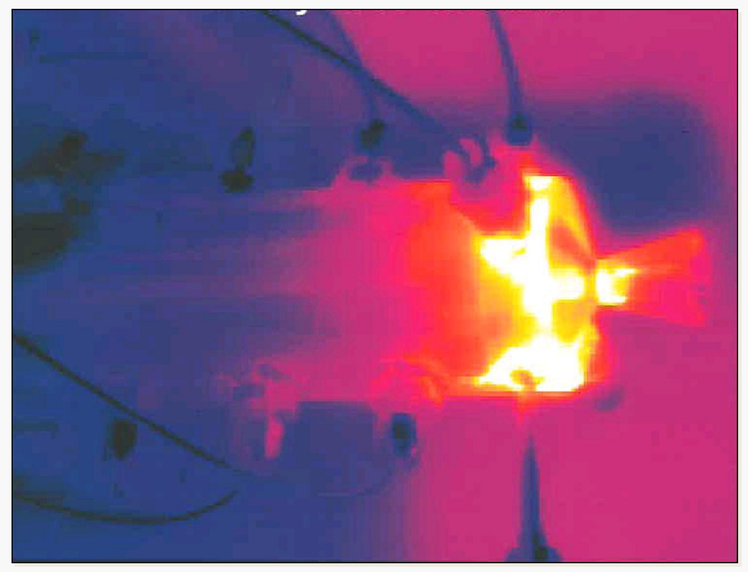


THRUSTER OVERVIEW

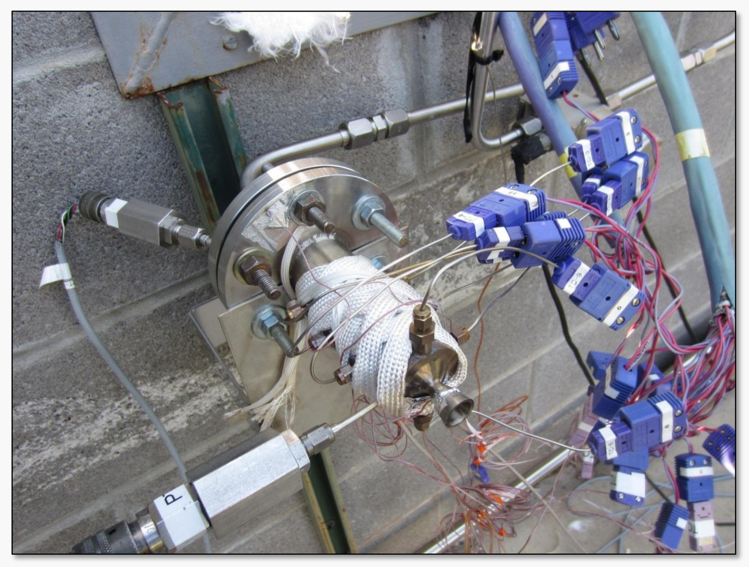
- 304 Stainless Steel microthruster (~6" overall length)
- Three Macor sleeves were machined to both insulate the catalyst and allow for variable catalyst length
- External heater used to preheat catalyst bed



THRUSTER TESTING



Thruster infrared image during testing



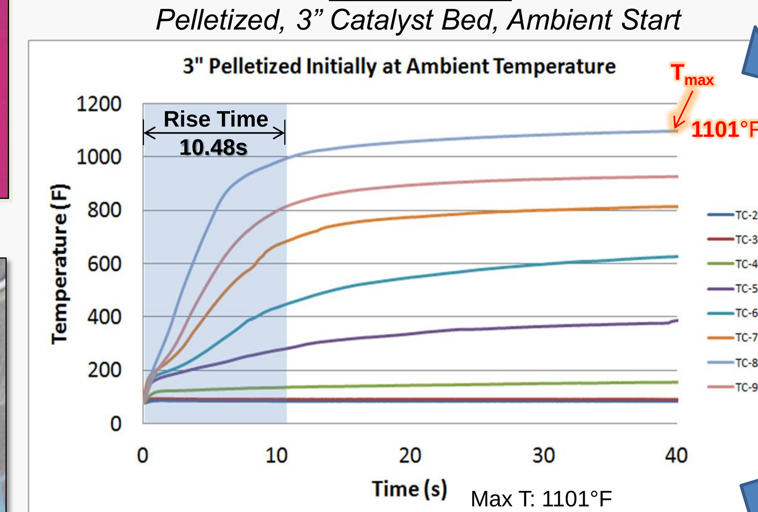
(15) E-type thermocouples, (3) 500 psi pressure transducers, (1) turbine flow meter were used to capture test data

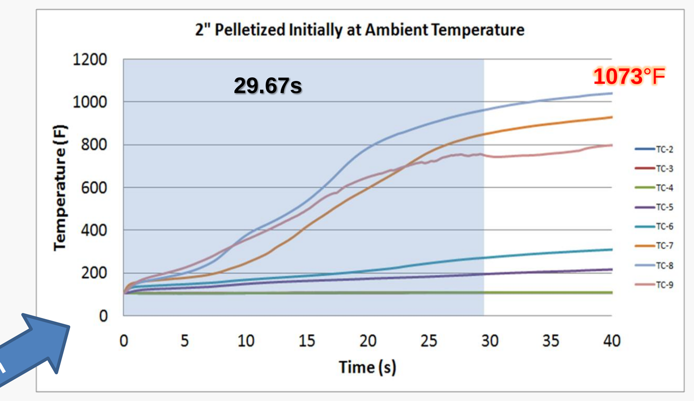
Varied Configuration Parameters:

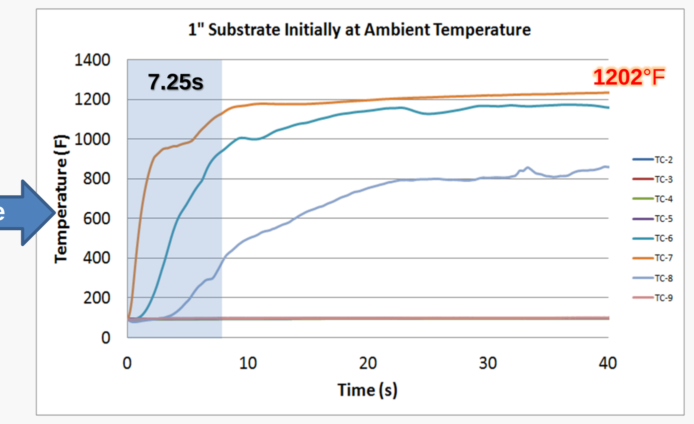
- Catalyst Type – Pelletized, Substrate
- Catalyst Length – 1", 2", 3" catalyst beds
- Catalyst Initial Temperature – Ambient, Pre-heat

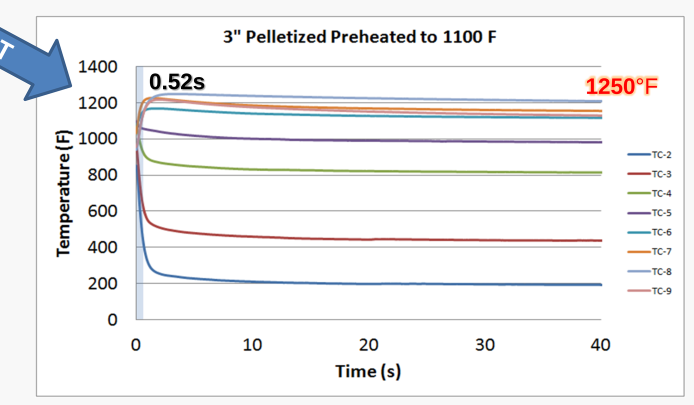
Baseline Test

Pelletized, 3" Catalyst Bed, Ambient Start









Compared Performance Parameters:

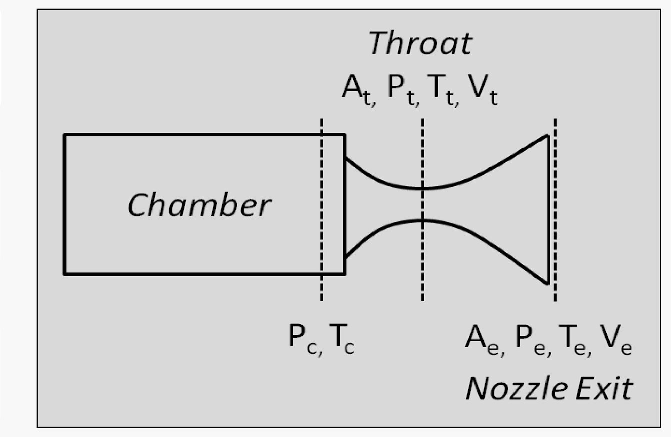
- Maximum Chamber Temperature (T_c)
  - *Maximum temperature during reaction*
- Temperature Rise Time
  - *Time for T_c to reach 90% of maximum*

DATA ANALYSIS

Known Parameters A_e, A_t

Measured Variables $P_a, P_c, T_c, \dot{m}$

Calculated Values P_e, V_e, T_e, F, I_{sp}



Test data analysis allowed for determination of thruster performance specifications. The following equations were used to find thrust and specific impulse:

$$\frac{A_t}{A_e} = M_e\sqrt{\left(\frac{1+\frac{\gamma-1}{2}}{1+\frac{\gamma-1}{2}M_e^2}\right)^{\frac{\gamma+1}{\gamma-1}}} \qquad \frac{P_e}{P_c} = \left(1+\frac{\gamma-1}{2}M_e^2\right)^{\frac{\gamma}{\gamma-1}}$$

$$F = A_tP_c\gamma\left[\left(\frac{2}{\gamma-1}\right)\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}\left\{1-\left(\frac{P_e}{P_c}\right)^{\frac{(\gamma-1)}{\gamma}}\right\}\right]^{\frac{1}{2}} + (P_e-P_a)A_e \qquad I_{sp} = \frac{F}{\dot{m}g_o}$$

Configuration	Thrust (lbf)	I_{sp} (s)
3" Pelletized, Ambient	4.41	195
3" Pelletized, Preheated	5.00	221
2" Pelletized, Ambient	4.07	180
1" Substrate, Ambient	0.87	134

FLOW ANALYSIS

Pressure drop across the catalyst bed:

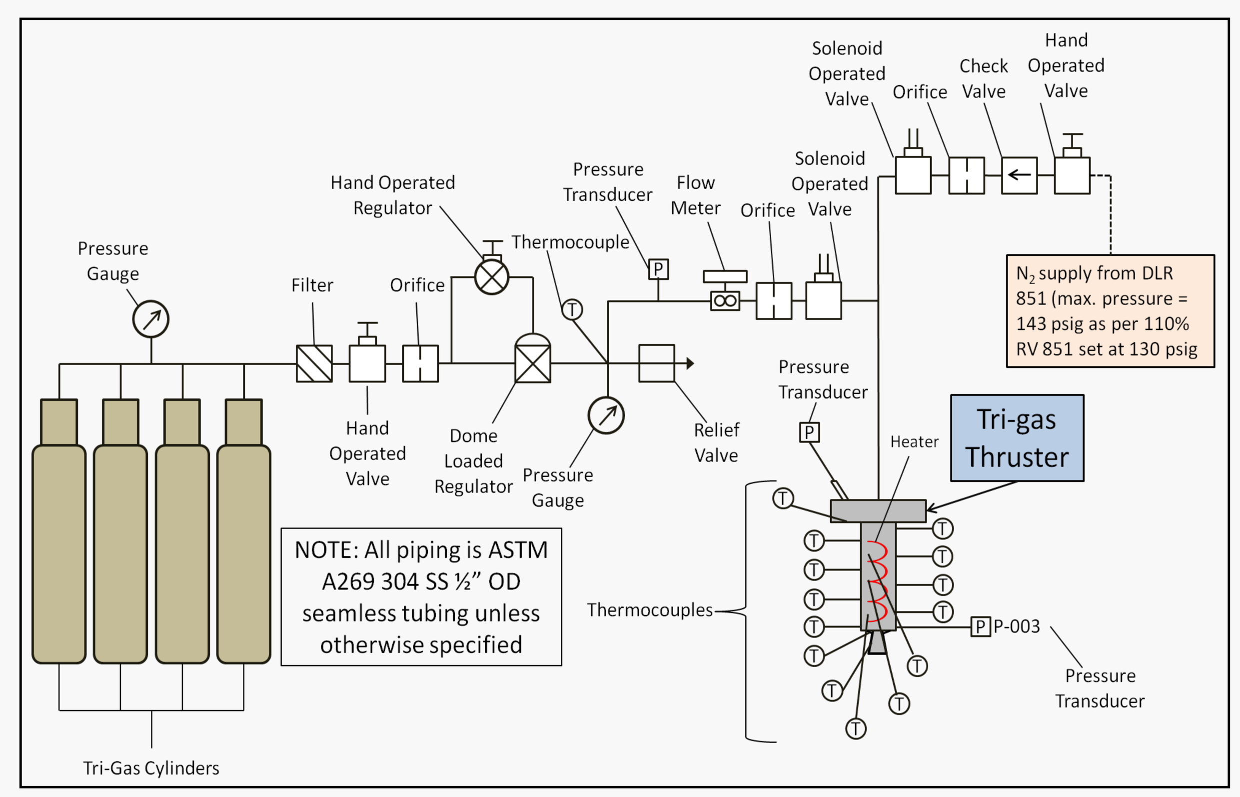
$$\Delta P = \frac{150L\mu V}{kgD^2}\frac{(1-\epsilon)^2}{\epsilon^3} + \frac{1.75L\rho V^2}{kgD}\frac{(1-\epsilon)}{\epsilon^3}$$

Catalyst Type	Catalyst Length (in.)	Estimated Pressure Drop (psi)	Actual Pressure Drop (psi)
Pelletized	3	16.5	14
Pelletized	2	11.54	10
Substrate	1	11	23-65 CRUSHED
Substrate	0.4	5	9-11

Component Sizing:

$\dot{m}$ through the orifice < $\dot{m}$ through the relief valve

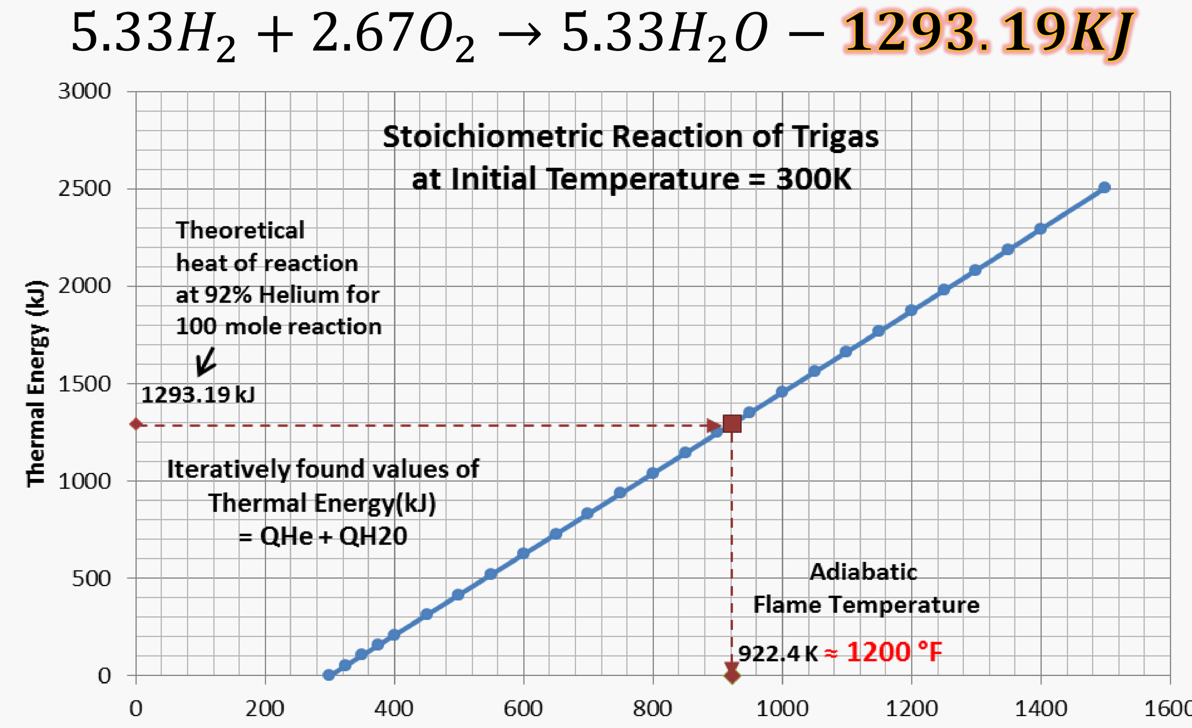
$$C_dA_2P_1\sqrt{\frac{g_c}{RT_1}\gamma\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}} < \frac{6.32\rho_1A_1CKP_1}{\sqrt{MTZ}}$$

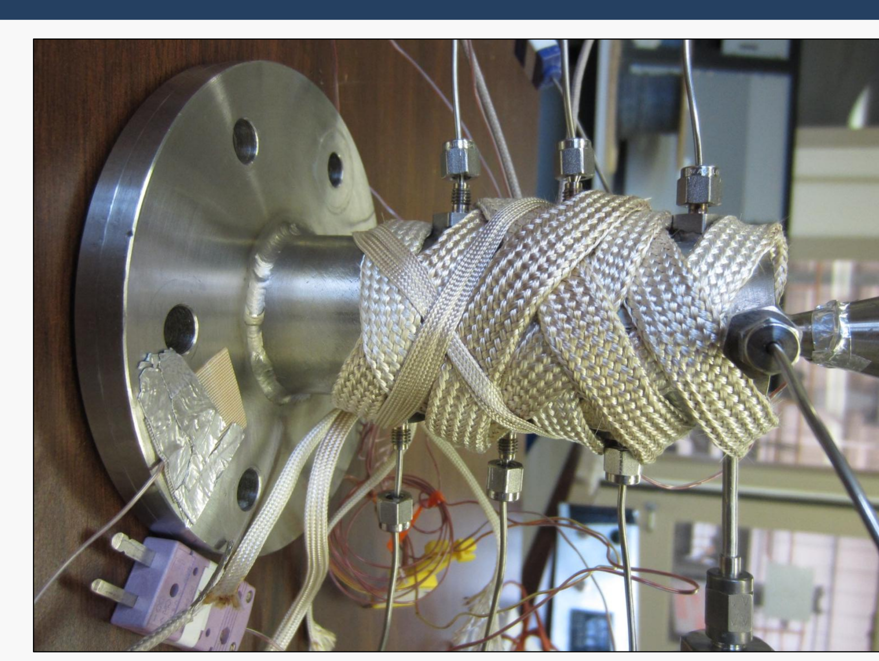


Tri-gas Thruster Flow Schematic

THERMAL ANALYSIS

$$5.33H_2 + 2.67O_2 \rightarrow 5.33H_2O - \mathbf{1293.19KJ}$$





A flexible external heater was implemented to heat the catalyst near the reaction's adiabatic flame temperature prior to flowing tri-gas

CONCLUSIONS

- Analysis of test results for both catalyst types suggests that the pelletized catalyst provides better performance when optimizing thrust and I_{sp}.
- Although the substrate catalyst demonstrated a shorter rise time, its low compressive strength required a 78% decrease in mass flow to avoid structural failure.
- It was determined that longer pelletized catalyst beds had a shorter rise time, which could be further minimized by pre-heating the catalyst bed.
- **Optimal configuration: 3 in. pre-heated pelletized catalyst**

Ongoing experiments seek to continue exploring reaction transients and study the substrate's structural integrity. Future experiments that might further this project's goals include testing of the following conditions:

- *Optimized catalyst bed length*
- *Hydrogen (fuel) rich tri-gas mixture*
- *Performance in simulated high altitudes*

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